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A COMPARISON OF PORTABLE ALUMINUM AND STANDARD WOODEN THERMOMETER SHELTERS

Arnold I. Finklin[1]

ABSTRACT

Presents and discusses results of a field test of a new model portable aluminum thermometer shelter near Missoula, Montana. Comparisons of daily maximum and minimum temperatures show this shelter to be quite suitable as a field-use alternative to the standard wooden shelter employed at climatological and fire-weather stations.

KEYWORDS: temperature measurement, thermometer shelters,
fire-weather equipment

A portable, collapsible, white-painted aluminum thermometer shelter has been an item of Forest Service, USDA, field equipment for about the past 15 years. This shelter, developed at the Northern Forest Fire Laboratory (NFFL), near Missoula, Montana, is described by the Forest Service, USDA (1964). Results of tests at several diverse locations were said to be generally satisfactory, considering the portability advantage and the sampling errors that may be encountered in field use. As compared with the wooden "cotton-region" shelter, which is the standard at climatological and fire-weather stations, the aluminum shelter gave daily maximum temperatures averaging mostly between 1.0° and 2.0°F (0.6° and 1.1°C) too high. The size of this assumed error, apparently resulting from absorption or reflection of solar radiation, was found to vary, overall, with the temperature or time of year. Minimum temperatures generally averaged a fraction of 1°F too low.

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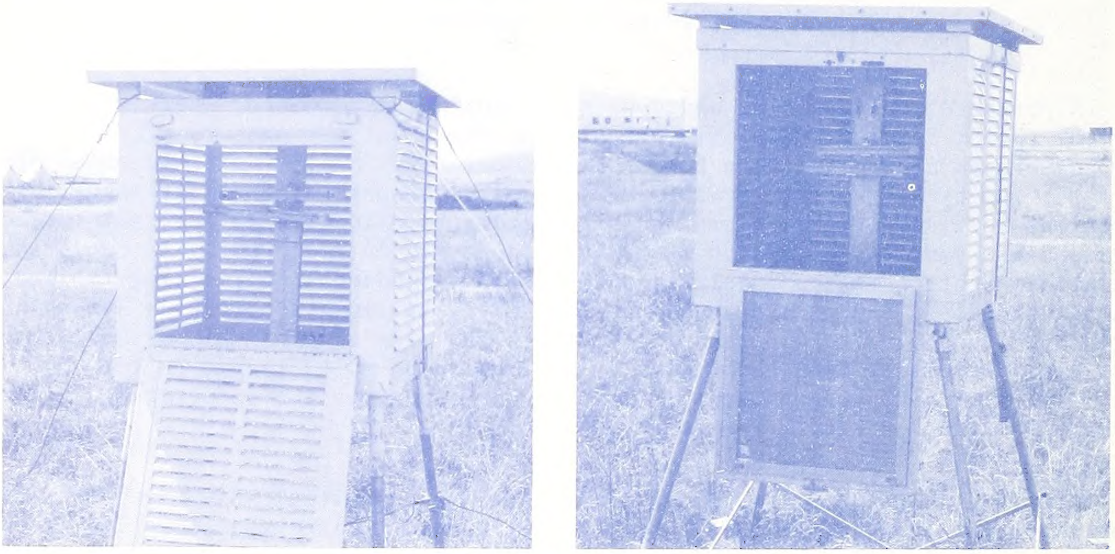
[1] Research Meteorologist, assigned to the Fire in Multiple-Use Management RD&A Program at the Intermountain Station's Northern Forest Fire Laboratory in Missoula, Montana.

A new model aluminum shelter was recently developed at the San Dimas Equipment Development Center in California. Aside from possible improvement in measuring air temperature, the new model is of sturdier construction (though only the floor is of thicker metal than before). This is largely a result of metal-framed panels of coarse-mesh wire screening fastened behind the louvered walls. There is also screening under the floor holes. The louvers themselves are somewhat closed, formed (stamped and pressed out) like those in the final specifications drawn for the earlier model. Some of the earlier shelters actually produced, however, have louvers with a more open, flared appearance. The interior of the newer shelter is unpainted, giving a grey, non-reflective property; the exterior has a glossy white enamel finish. Dimensions are identical to those of the earlier model, 2 by 2 by 2 ft (0.6 by 0.6 by 0.6 m), and the double roofing is about the same.

The new shelter was dispatched to the NFFL in July 1976, at which time comparisons were begun with a version of the earlier model and with two "cotton-region" shelters. This report evaluates the newer shelter, documenting and examining the results of at least one year's comparisons. A brief summary of the results is included in an article by William C. Fischer, submitted to "Fire Management Notes" (Forest Service, USDA). Further details about the shelter can be obtained from the San Dimas Equipment Development Center, 444 E. Bonita Ave., San Dimas, CA 91773.

COMPARISON PROCEDURES

The new aluminum shelter (referred to here as A2) and an available older unit (A1), having the flared-type louvers, were placed near two already exposed wooden shelters over a fescue-wheatgrass surface about 100 to 120 yards (90 to 110 m) west of the NFFL; see figures 1 and 2. The relative setup, with the two aluminum shelters 15 ft (5 m) apart, is depicted in figure 3. The wooden shelters differ somewhat, even though both were constructed to U.S. Weather Bureau (now National Weather Service) specifications. That of more recent make (referred to here as W2), situated inside a fire-weathe station enclosure, has a somewhat less open, more slanted louver design and much narrowe space between the floorboards as compared with the older shelter (W1); the latter is about 60 ft (18 m) farther west and has been used during the past 10 years for year-roun climatological records.



A1

A2

Figure 1.--Closeup of new model aluminum shelter, A2, and older aluminum shelter, A1, showing difference in louver construction and the unpainted interior of A2.

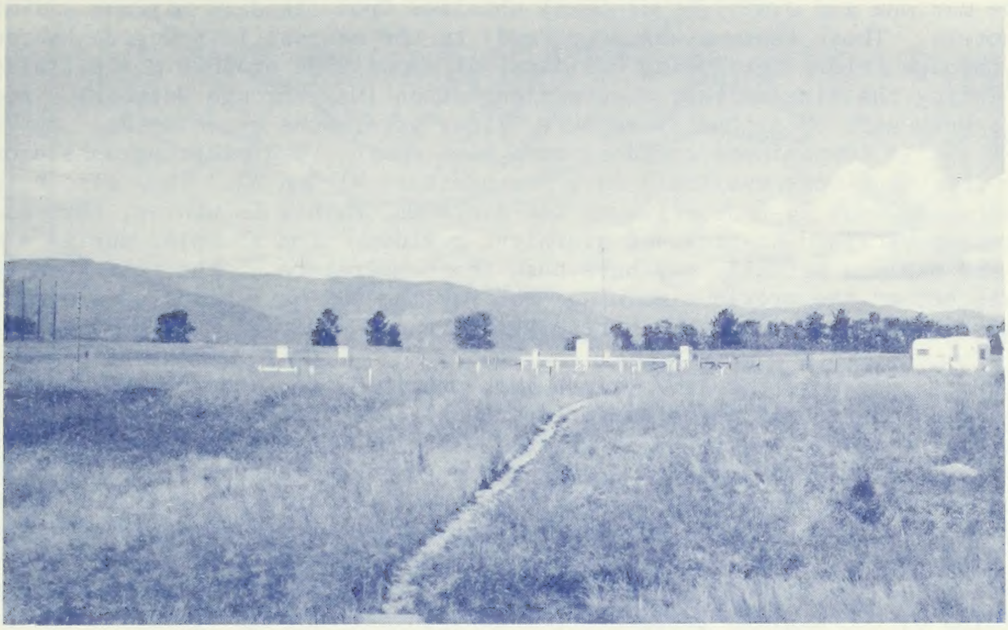


Figure 2.--View (facing west) of thermometer shelter test location, near Missoula, Montana; two aluminum shelters are at left, two wooden shelters at right.

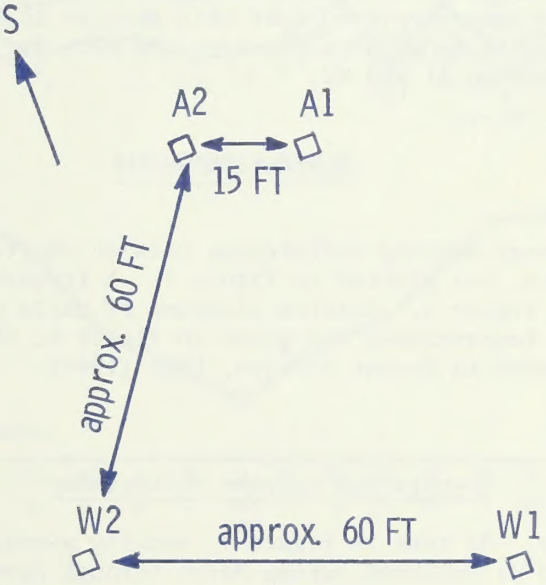


Figure 3.--Relative location of four thermometer shelters in field about 100-120 yards (90-110 m) west of Northern Forest Fire Laboratory. "A" denotes aluminum shelter, "W" wooden ("cotton-region") shelter, "1" older model, "2" newer model.

Comparisons between the shelters are based on the daily extreme temperatures (daytime maximum and overnight minimum) obtained from standard maximum and minimum thermometers. These instruments were read, to the nearest 10th degree Fahrenheit, Monday through Friday (excluding holidays) at about 0900 or 1000 m.s.t., also near 1400 m.s.t. during the fire-weather observation season (May through October). Additional readings were made occasionally on late Friday afternoons or weekends. Approximately 15 to 20 usable comparisons could be made each month. Hygrothermographs provided a reading check but were available only for shelters W1 and W2. They also helped in spotting occasional 24-hour maximums and minimums, mainly in winter, that did not occur during the prescribed daytime and overnight periods. For example, during a warming trend, the minimum actually may have been the temperature at the time when the thermometer was set on the previous morning; the maximum may have occurred around the current morning's observation time. Such readings were not used.

Thermometers were checked against each other and for accuracy by their current readings (and those of a psychrometer dry bulb) during cloudy and breezy conditions; also several times by immersion in stirred water of varying temperatures. Three of the four maximum thermometers had no detectable error; the remaining one, switched between shelters A1 and A2, required a correction of -0.2° to -0.4°F (-0.1° to -0.2°C) at temperatures below 80°F (27°C). All four minimum thermometers had slight, rather constant errors that were not due to any bubble formation in the liquid column; readings were corrected by adding between 0.2° and 0.6°F (0.1° and 0.3°C). An occasional problem was the sliding of the minimum thermometer index pin due to wind vibration of the shelter. This sliding occurred with all shelters except W2 but was mostly alleviated by a near-horizontal setting of the thermometer and firmer bracing of shelter supports. Larger errors from this source were obvious and readings could safely be rejected, but small ones such as 1°F (about 0.6°C) could possibly pass through our data inspection.

Comparisons presented here use shelter W2 as the primary standard; as shown later, this type appears to give most closely the true (outside shelter) air temperature. The comparisons cover the period from July 16, 1976, through January 31, 1978. There is, however, a gap of more than 3 months--October 1976 through mid-January 1977--in those involving A2, due to the temporary return of this shelter to San Dimas Equipment Development Center. Estimates or adjustments could be made for this missing period, using the comparisons between A1 and W2.

RESULTS

The courses of average monthly differences between shelters, together with the extreme daily differences, are plotted in figure 4. A frequency distribution of daily differences is shown in figure 5. Scatter diagrams of daily differences vs. corresponding maximum and minimum temperatures are given in figure 6; this allows some comparison with the figure 2 presented in Forest Service, USDA (1964).

Average and Extreme Differences

Maximum temperature.--As seen in figure 4, monthly average differences of +0.7° to +1.4°F (+0.4° to +0.8°C) occurred during March through September between the maximum temperatures inside shelters A2 and W2; average differences during autumn and winter months were mostly +0.4° to +0.5°F (+0.2° to +0.3°C) or less. There is not, however, a smooth relationship with the monthly average maximum temperature. Extreme daily differences reached about +3.0°F (+1.7°C) in June and July (1977) and also in January (1978). The available monthly differences averaged mostly between 0.6° and 1.1°F (0.3° and 0.6°C) smaller than those between shelters A1 and W2.

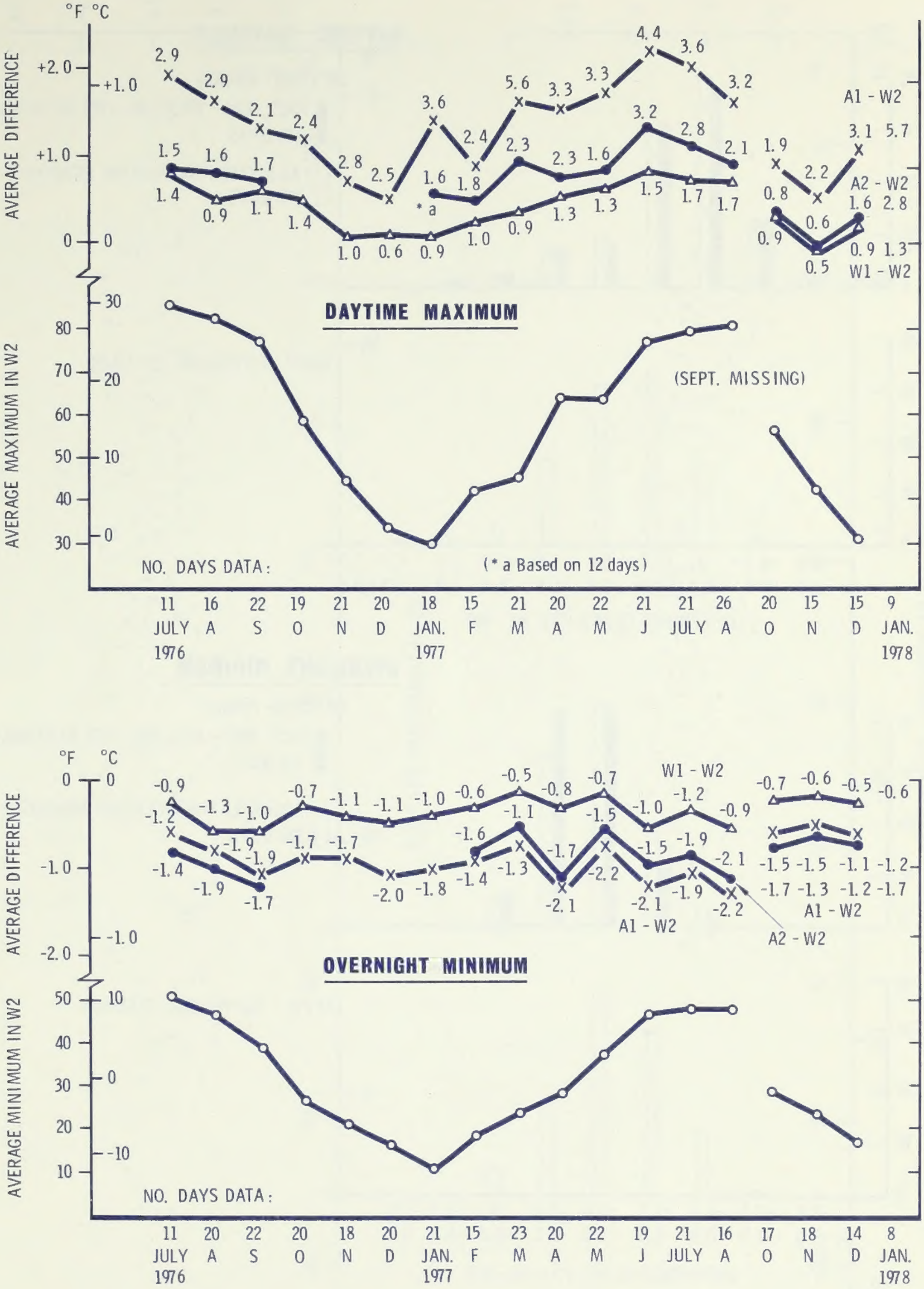


Figure 4.--Average monthly daytime maximum and overnight minimum temperatures inside "cotton-region" shelter (W2) and differences with other shelters (see legend, figure 3). Numbers adjacent to points are extreme differences (°F) during month, July 1976-January 1978 (September 1977 missing). Heavy dot denotes A2-W2; X, A1-W2; triangle, W1-W2.

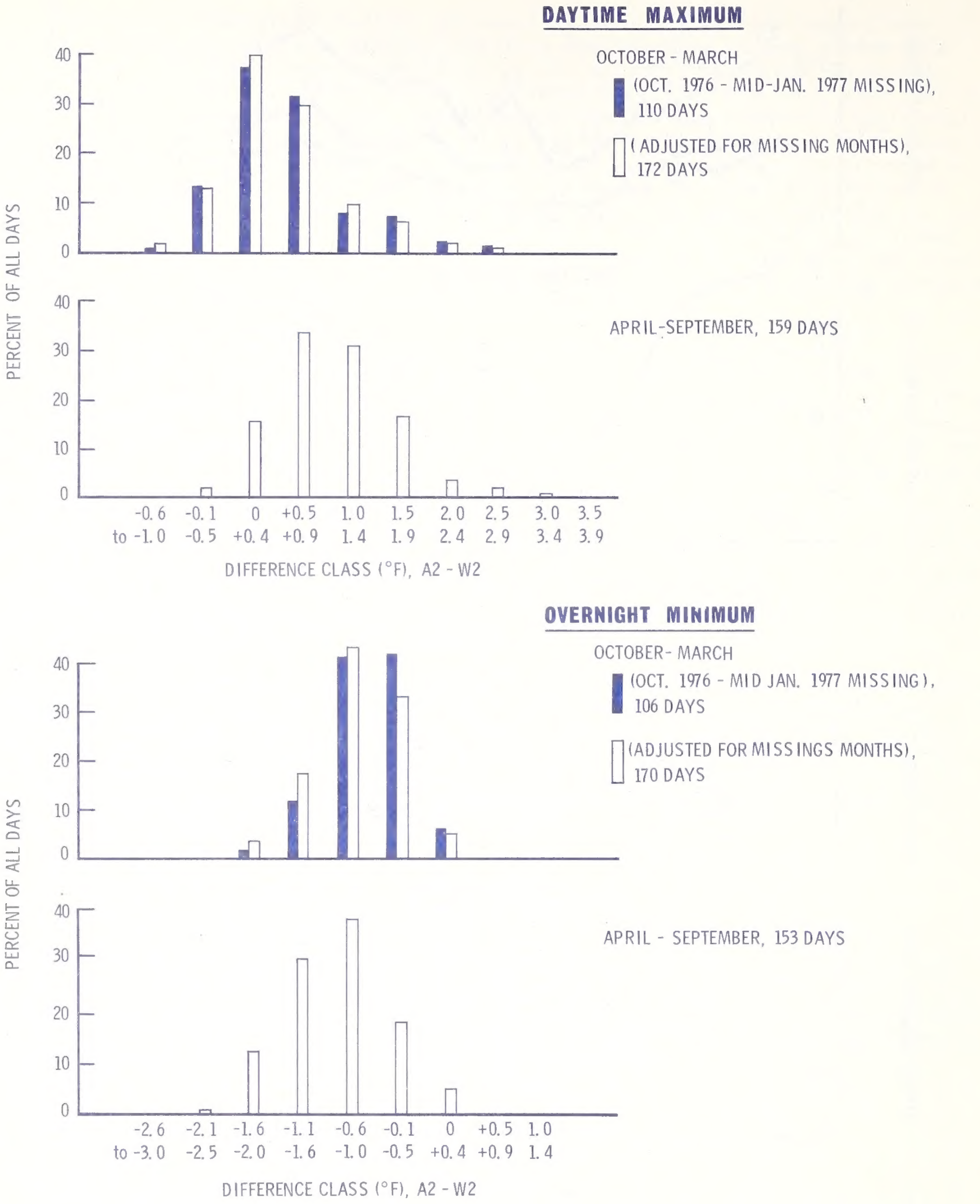


Figure 5.--Percent frequency of daily differences in temperature between shelters A2 and W2, by 6-month periods, October-March and April-September. Upper panel: daytime maximum. Lower panel: overnight minimum. Based on readings during July 1976-January 1978. Adjustment for missing months (October 1976 through mid-January 1977) made with aid of differences between shelters A1 and W2. Differences are given by classes having 0.5°F interval; multiply values by 0.56 for conversion to °C.

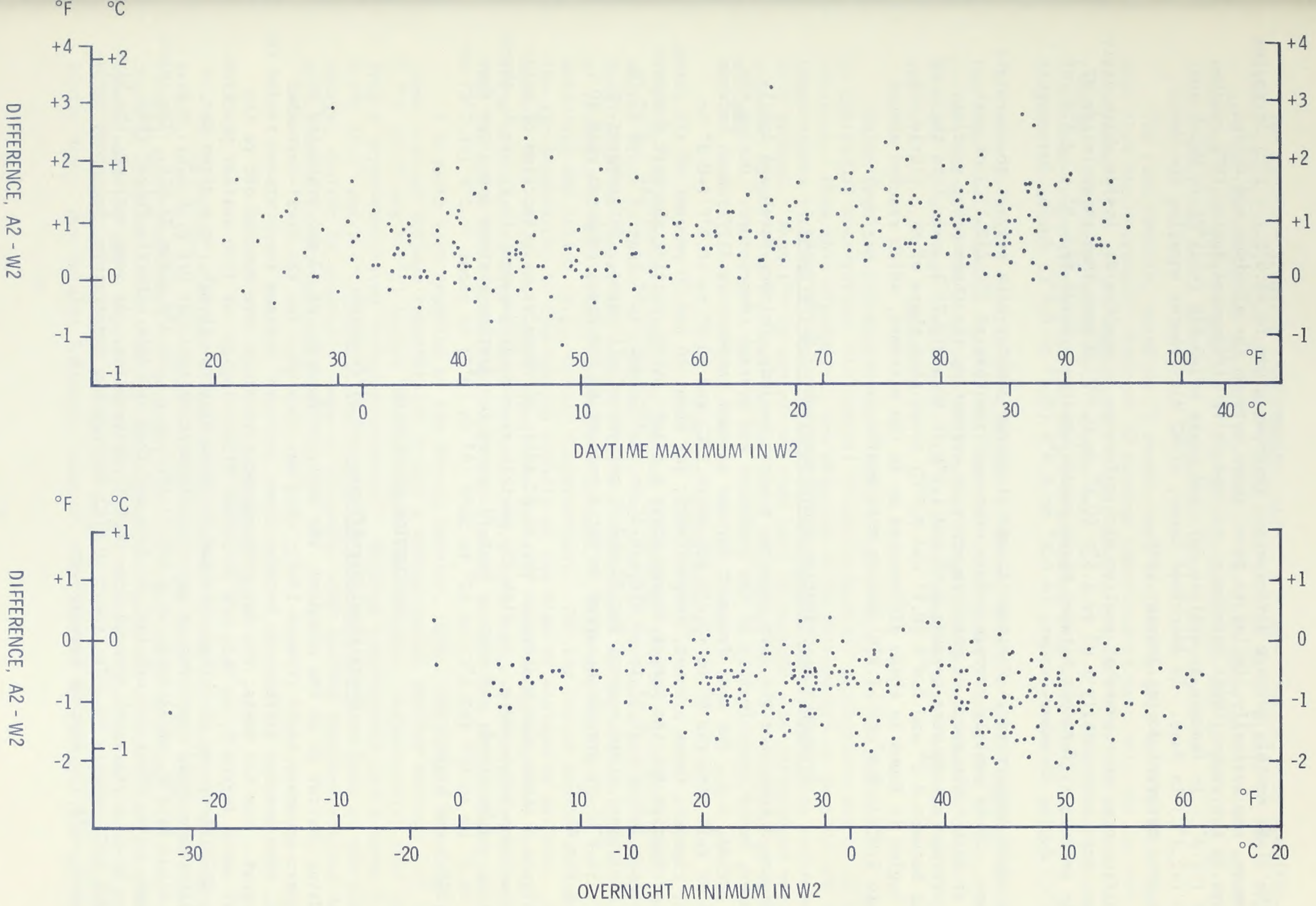


Figure 6.--Differences in daytime maximum and overnight minimum temperatures, shelters A2-W2, vs. maximum and minimum readings in shelter W2. Based on days during July-September 1976 and January 1977-February 1978.

The A1-W2 monthly average differences, reaching close to +2.0°F (+1.1°C) in spring and summer, are basically similar to those shown between the aluminum and wooden shelters in the above (1964) reference; extreme daily differences during 1977 reached +3.6°F (+2.0°C) in January as well as July and peaks of +5.6°F (+3.1°C) in March and +4.4°F (+2.4°C) in June. As described later, A1-W2 differences equaling the March figure were observed during January 1978.

Differences were somewhat smaller with reference to shelter W1, inside which daily maximums were occasionally 1.0° to 1.5°F (0.6° to 0.8°C) higher than those inside W2. Monthly average differences between these wooden shelters ranged from 0° to 0.3°F (0° to 0.2°C) during November-January to 0.8° or 0.9°F (0.4° to 0.5°C) during June-August.

Minimum temperature.--Shelters A2 and A1 appear similar with respect to overnight minimums. Their monthly average values were mostly within ±0.2°F (±0.1°C) of each other or within the range of possible error in correcting the thermometer readings. These average values were between 0.5° and 1.2°F (0.3° and 0.7°C) lower than those of W2; and between 0.2° and 0.9°F (0.1° and 0.5°C) lower than those of W1. Little seasonal regime is found in these differences or in the extremes, which reached around -1.5° to 2.0°F (-0.8° to -1.1°C) during most months.

Frequency Distribution and Dispersion of Differences

Figure 5 separates the data into two 6-month periods, October-March and April-September, based approximately on the equinoxes and average temperature. During the first period, e.g., the most frequent daytime maximum temperature differences between A2 and W2 fall into the 0° to +0.4°F (0° to +0.2°C) and +0.5° to +0.9°F (+0.3° to +0.5°C) classes; these account, respectively, for about 40 and 30 percent of all cases. The distribution for the warmer season shows a slight shift, putting the most frequent differences into the +0.5° to +0.9°F (+0.3° to +0.5°C) and +1.0° to +1.4°F (+0.6° to +0.8°C) classes; these account for 33 and 30 percent of all cases. Differences of +2.0°F (+1.1°C) or greater occurred on but 4 percent of the days, compared with 40 percent for A1-W2.

Figure 6 shows wide scatter in the A2-W2 daily differences as a function of maximum or minimum temperature. As with the monthly average differences in figure 4, there is only a slight trend. At most, a best-fit curve for daytime maximum may slope from about +0.5° or +0.6°F (+0.3°C) at 32° to 50°F (0° to 10°C) to about +1.2°F (+0.7°C) at 80°F (27°C) and higher.

DISCUSSION OF RESULTS

Statistical Significance of Differences

Using shelter W2 as the standard, the daily performance of A2 was evaluated by chi-square accuracy tests (Freese 1960); this was done only for the April-September period, when average differences between these shelters' maximum temperatures tended to be largest. For the tests, the daily thermometer readings were rounded off to the nearest whole degree F, as they are in actual climatological or fire-weather practice. The A2-W2 differences were then obtained in whole degrees--though, on a given day, a 1°F difference could represent an actual difference as small as 0.1°F (0.1°C), e.g., 74.5° minus 74.4°F, or as large as 1.9°F (1.1°C), e.g., 76.4°F minus 74.5°F. The tests were made using first the original A2 data and then the data with the "bias" (the average A2-W2 difference) removed from each A2 observation. As seen earlier, the bias (rounded off) amounts to +1°F (about +0.6°C) for maximum temperature throughout April-September; -1°F for minimum temperature.

Two separate accuracy requirements, strict and more lenient, were specified; these asked, respectively, that each day's data from shelter A2 be within 1° and 2°F of the W2 data at the 95 percent probability level. The chi-square calculations actually used limits of 1.4°F (0.8°C) and 2.4°F (1.3°C). To avoid bias due to possible day-to-day persistence, the tests used data sampled at least 3 days apart.

The test results, based on 70 sample days (as well as all 161 available days), show that the originally observed A2 maximum temperatures meet only the lenient accuracy requirement; the strict requirement is met, however, when 1°F is subtracted from each reading. Similarly, based on 67 sample days (as well as all 153 available days), the A2 minimum temperatures meet the strict requirement only when 1°F is added to the original values.

More favorable results are obtained if the A2 data are tested against those from the older design wooden shelter, W1; many of these shelters continue in use. Relative to this standard, the observed, uncorrected A2 maximum and minimum temperatures both meet the 1°F accuracy requirement; the April-September "biases" are only +0.25°F (0.1°C) and -0.6°F (-0.3°C), respectively.

Aside from the chi-square test results, which relate to the reliability placed in an individual observation, the overall (time-integrated) performance may be of greater interest. From this standpoint, the observed A2-W2 differences in rounded-off maximum temperatures exceeded 1°F on 22 percent of the spring-summer days; they exceeded 2°F on 2 percent. When 1°F is subtracted from each A2 maximum, the differences with W2 exceeded only 1°F on 2 percent of the days; similarly, when 1°F is added to each A2 minimum.

Sources of Differences

The differences in readings between thermometer shelters (assuming that instrumental error is absent or removed) have two possible explanations: differences in errors from radiation (solar and terrestrial) and differences in lag effects (involving rate of response to outside-air temperature changes). These are both related to the shelter materials and design (e.g., louver construction). The lag factor may be dominant when the air temperature is fluctuating rapidly at the time of maximum or minimum. Overall, however, the radiation factor appears to prevail. Dominating radiation errors are found with the standard wooden shelters (e.g., by sling psychrometer comparisons), and thus the above differences must represent greater errors from the aluminum shelters.

A 4-month test reported by the Forest Service, USDA (1964), at a Maryland site shows average maximum temperatures inside a cotton-region shelter between 1.3° and 0.7°F (0.7° and 0.4°C) higher (during August and November, respectively) than those from a force-ventilated "telepsychrometer." Minimum temperatures are between 0.3° and 0.7°F (0.2° and 0.4°C) lower. The shelter in this test may have been of the older W1 design; shelter W2 generally compares favorably with another force-ventilated device, as discussed in the following section.

Radiation Effects

As indicated in figure 6, the deviations of shelter A2, mainly from radiation errors, vary with the individual day and night (and hour). They should be least under cloudy, windy conditions and greatest when there are clear skies and little or no wind. Overall, greatest effects on daytime temperatures might be expected in spring and summer when the sun's rays are most direct and intense. The presence of a highly reflective snow cover can lead to equally large effects on sunny (or bright though cloudy) winter days. Our results indicate, however, that shelter A2 is much less affected than shelter A1 by this condition, which on a late March day brought to A1 its largest error during 1977 (+5.6°F, or 3.1°C); similarly large errors occurred on 2 days in January 1978.

As already shown, the radiation errors of shelter W2 are apparently smaller than those of shelter W1. An idea of the W2 error was sought by comparing its data with those from a "hygrothermometer" (designated here as HT) at the nearby Missoula airport, located about 1.0 mile to the southeast. This electronic device, having a shielded sensor exposed on the field (at a height of 4 ft, or about 1.2 m), has been used by the National Weather Service for the official temperatures at its airport stations since about 1960. Forced ventilation practically eliminated errors from radiation. Its response time, or lag, is adjusted to equal that of the standard liquid-in-glass thermometers. Errors can, however, arise with respect to calibration; a tolerance of ±1°F (about ±0.6°C) is specified. Such errors should, over a space of years, average near zero but will be systematic over durations that can cover a few months or longer before the equipment is adjusted. The standard, once-weekly checking procedure is such that errors of 2°F (1°C) can actually occur for extended durations; at many stations, it involves comparisons with a psychrometer inside a roof-mounted wooden shelter.

Because of differences in local environment, exact agreement between the HT and W2 daily and average temperatures would not be expected even if there were no errors from radiation or the instruments. Nevertheless, a sample of 104 spring and summer days (46 during July-September, 1976, and 58 during May 1-July 24, 1977) yielded an average W2-HT difference of -0.3°F (-0.2°C) in daily maximum temperature (-0.2° and -0.4°F, or -0.1° and -0.2°C, for the two respective periods). Individual daily differences ranged from -2° to +2°F (-1° to +1°C) and were zero on 43 (or 41 percent) of the days. The afternoon radiation error of shelter W2 might thus appear negligible, overall; or at least there is a good balance between opposing effects of radiation and shelter lag. The W2 site does not have the possible pavement effects of the airfield, which may contribute to the slightly higher average temperature from HT (itself situated over a natural surface). In the cooler months, however, the W2-HT differences are usually positive in sign during sunny days with snow on the ground and very light wind, with differences commonly 2°F (1°C) or more.

A sample of 96 overnight minimum temperatures (44 and 52 nights during the above two periods) gave an average W2-HT difference of -0.8°F (-0.4°C), with -0.6° and -0.9°F (-0.3° and -0.5°C) for the respective periods. Individual differences ranged from -4°F (-2°C), on a single occasion, to +2°F (+1°C). Site factors may be responsible for about half of this negative-sign average difference.

Radiation Error and Shelter Design

Finally, we may ask why the various shelters perform differently. Explanations offered here are based mainly on the field results and familiar physical principles, rather than laboratory-type tests.

An ideal thermometer shelter or screen should protect thermometers from direct and indirect radiation (as well as from precipitation) while allowing adequate ventilation. The airflow through the louvers serves both to communicate the ambient air temperature to the thermometers and to remove heat absorbed by the shelter (MacHattie 1965, World Meteorological Organization 1971). From our results, it appears that the open, flared-louver construction of some of the earlier aluminum (A1) units allows entry of reflected solar radiation. Added to this may be terrestrial (outgoing, infrared) radiation emitted from the sunlit ground surfaces. The narrower louver openings and the wire-mesh backing of A2 allow less direct airflow but, overall, this apparently is well balanced by the reduced entry of radiation. The high-gloss white exterior of A2 appears effective against absorption of radiation. The unpainted, gray interior of this shelter should be an advantage over the previous white-painted interior, which would more easily reflect entered radiation to the thermometers.

The large holes in the floor of shelter A1 were suspected as another entry for radiation while contributing little to ventilation. The importance of upward radiation is shown by MacHattie (1965) in shelter experiments in Canada. Such holes are found in A2, but the open area is interrupted somewhat by the wire mesh. To test the above speculation, the floor of A1 was on July 27, 1977, entirely covered by a barrier of 3/4-inch plywood. Maximum-temperature differences through August 18 were then compared with those before this treatment. The average A1-W2 difference, based on 20 days, was found to be +2.0°F (+1.1°C); the average A1-A2 difference, +0.8°F (+0.4°C). These differences are nearly identical to those during the several preceding spring and summer months, as seen in figure 4. Further, comparisons during the following winter showed that this treatment brought no reduction in A1-W1 differences with snow on the ground; e.g., extreme differences of +5.7° and +5.5°F (3.2° and +3.1°C) were observed during January 1978, while corresponding A2-W2 differences were +1.1° and +2.8°F (+0.6° and +1.6°C).

Thus, the improvement of A2 over A1 evidently results from the louvered wall construction and possibly also from differences in paint (or its absence). Paint is apparently not a factor in the improvement of W2 over W1; no change in average temperature differences is evident following identical new coats given to these wooden shelters during early June 1977. Again, the louver design of W2 appears more favorable.

SUMMARY AND CONCLUSIONS

The results of about 15 months' comparison near Missoula, Montana, show that a new model portable aluminum thermometer shelter (referred to here as A2) performs well as a field-use alternative to the standard wooden "cotton-region" shelter empoyed at climatological and fire-weather stations. Differences in afternoon (or at least daily maximum) temperature, attributed mainly to radiation effects, average about one-half those of an earlier aluminum unit (A1). Evaluation was made with reference to a more recent design wooden shelter (W2), which, at least in the absence of a reflecting snow cover, generally gives readings approaching those of the true (outside-shelter) air temperature.

In the Missoula climate, the assumed errors raise the average observed A2 maximums between approximately 0° to 0.5°F (0° to 0.3°C) in cloudy, late autumn and early winter months and upward to 1.0° to 1.4°F (0.6° to 0.8°C) during spring and summer months. These average values depend largely on the number of sunny days and the intensity of the incoming (or reflected) solar radiation. Errors as large as +1.5° to +3.0°F (+0.8° to +1.7°C) do occur on individual days throughout the year. Shelter A1 gave extreme errors of between +5.5° and +5.7°F (+3.1° and +3.2°C) on 3 days (1 in March and 2 in January) under a combination of sunshine, very light wind, and snow cover. Inside A2 the errors on these same days ranged from +1.1° to +2.8°F (+0.6° to +1.6°C); the W2 maximums were themselves somewhat too high.

At night, outgoing radiational cooling of the shelter is the main factor in lowering the average observed A2 minimums below those of W2. The difference, on a monthly basis, averaged between -0.5° and -1.2°F (-0.3° and -0.7°C), with little seasonal regime; this represents little or no improvement over shelter A1. Extreme deviations occasionally reach -1.5° to -2.0°F (-0.8° to -1.1°C); these appear to be influenced in part by differences in shelter lag under conditions of rapidly fluctuating air temperatures.

The accuracy or reliability of the A2 readings on a daily basis, relative to W2, was examined by chi-square tests performed for the warmer portion of the year, when the portable shelter may find its greatest use. These tests indicate that, during spring and summer, subtracting 1°F (about 0.6°C) from the rounded-off observed A2 maximum should result in accuracy within 1°F at the 95 percent probability level; otherwise, accuracy will be within 2°F (about 1.1°C) at this probability level. A similar result occurs with respect to adding 1°F to the rounded-off observed minimum temperature.

The performance of A2 is in closer agreement with that of an earlier design wooden shelter (W1), still serving many stations. In fact, averaged over the year, the observed A2-W1 maximums differed by only +0.2°F (0.1°C); the W1-W2, by +0.5°F (0.3°C). Chi-square tests using W1 as the standard would show the uncorrected A2 daily maximums and minimums both within 1°F accuracy at the 95 percent probability level.

Thus, from a practical standpoint, the temperature (and relative humidity) data obtained from the new aluminum shelter should be adequate without correction. If there is interest in closely comparing average temperatures (e.g., 10-day or monthly) with those from standard reporting stations, the above details indicate the range of corrections that may apply. Possible errors of uncorrected instruments may, however, either add to or reduce those ascribed to radiation.

The favorable results from this point comparison should generally apply for at least the warmer part of year in other portions of the United States. Some variation in exact figures can be expected, related to differences in sunshine and windspeed (and ground surface) factors.

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